UNIVERSITEIT GENT

Applied Mathematics Biometrics and Process Control

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Adequate Complexity for Biofilm Systems Modelling

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Biofilms: Modelling and Analysis of Structure and Activity

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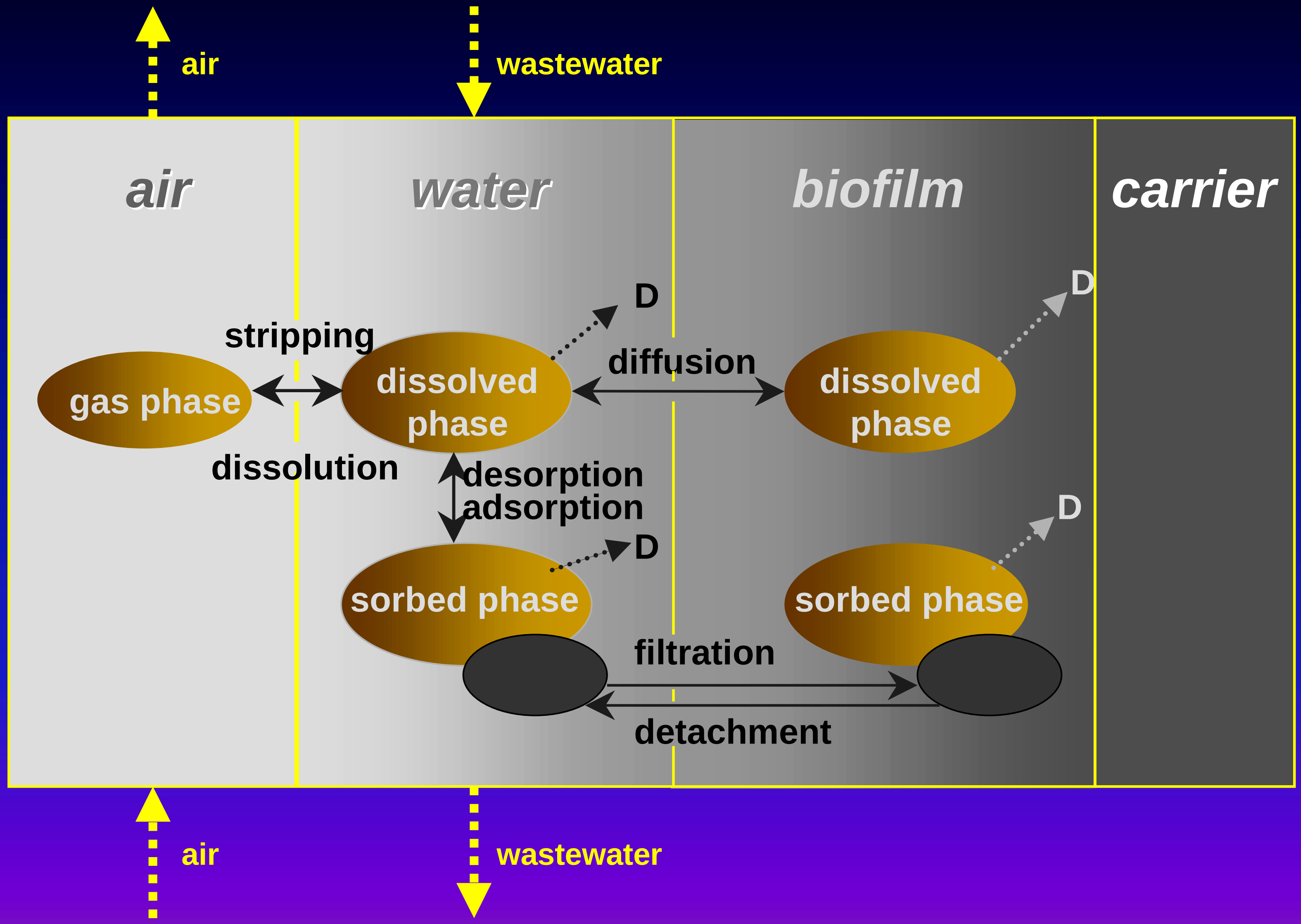
Cases Studies with Biofilm Models

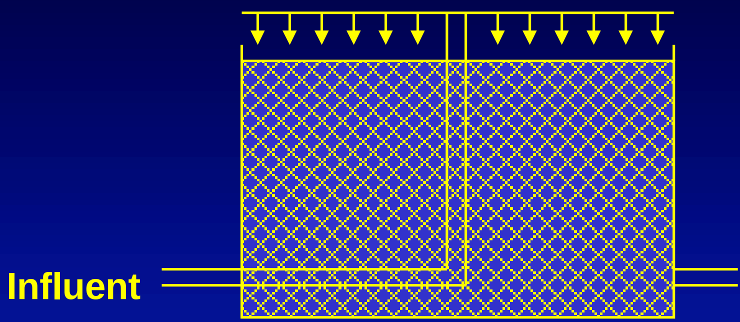
- Biofilm Reactors
- Why Model Biofilm Systems
- Biofilm Models Available
- Practicle Modelling Needs and Difficulties
- Case Study 1 and 2
  - The Aim
  - Model Building, Extension and Implementation
  - Results
- Conclusions

Biofilm Reactors

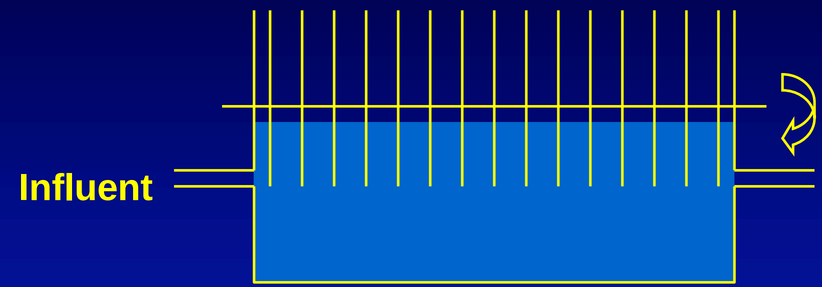


Some Biofilm Reactor Types

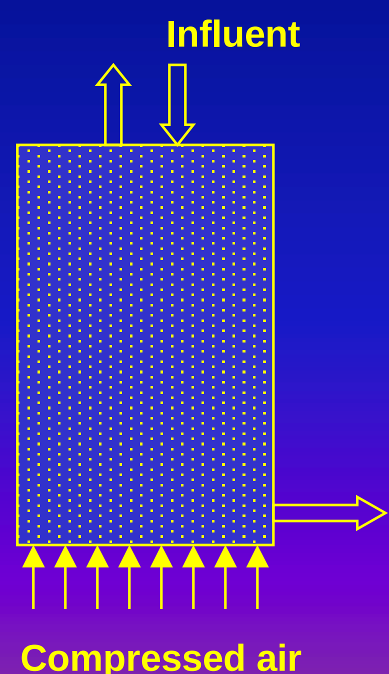
Trickling filter



Rotating biological contactor



Aerated submerged filter



Why Model Biofilm Systems

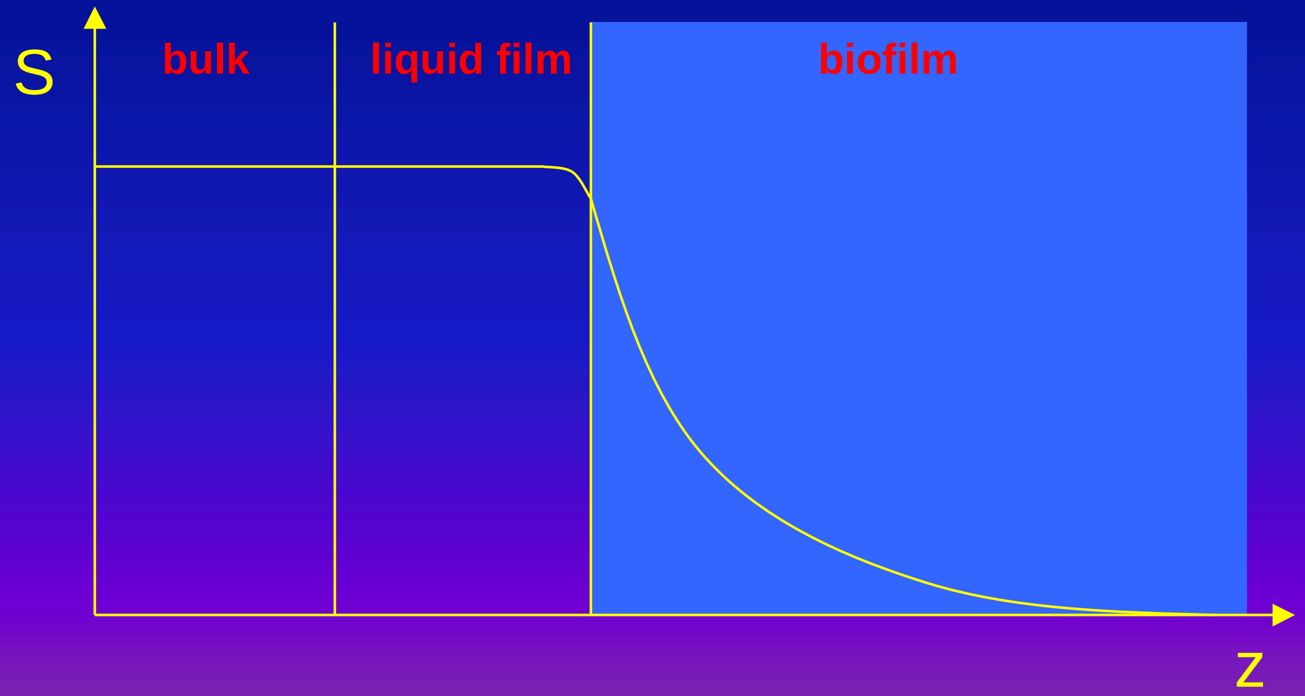
- Models are tools to develop understanding of complex interactions in biological systems

- Model applications
  - Qualitatively: improve general system understanding
  - Quantitatively: describe dynamic system responses

- Very few models used by practitioners (WWT)
  - Task: clarify when mathematical models can be helpful

Biofilm Models Available (1)

- 1D models focussing on substrate gradients (uniform biomass distribution)
  - Describe mass transport limitations to the biofilm
  - Analytical solutions or ODE-models: relatively simple



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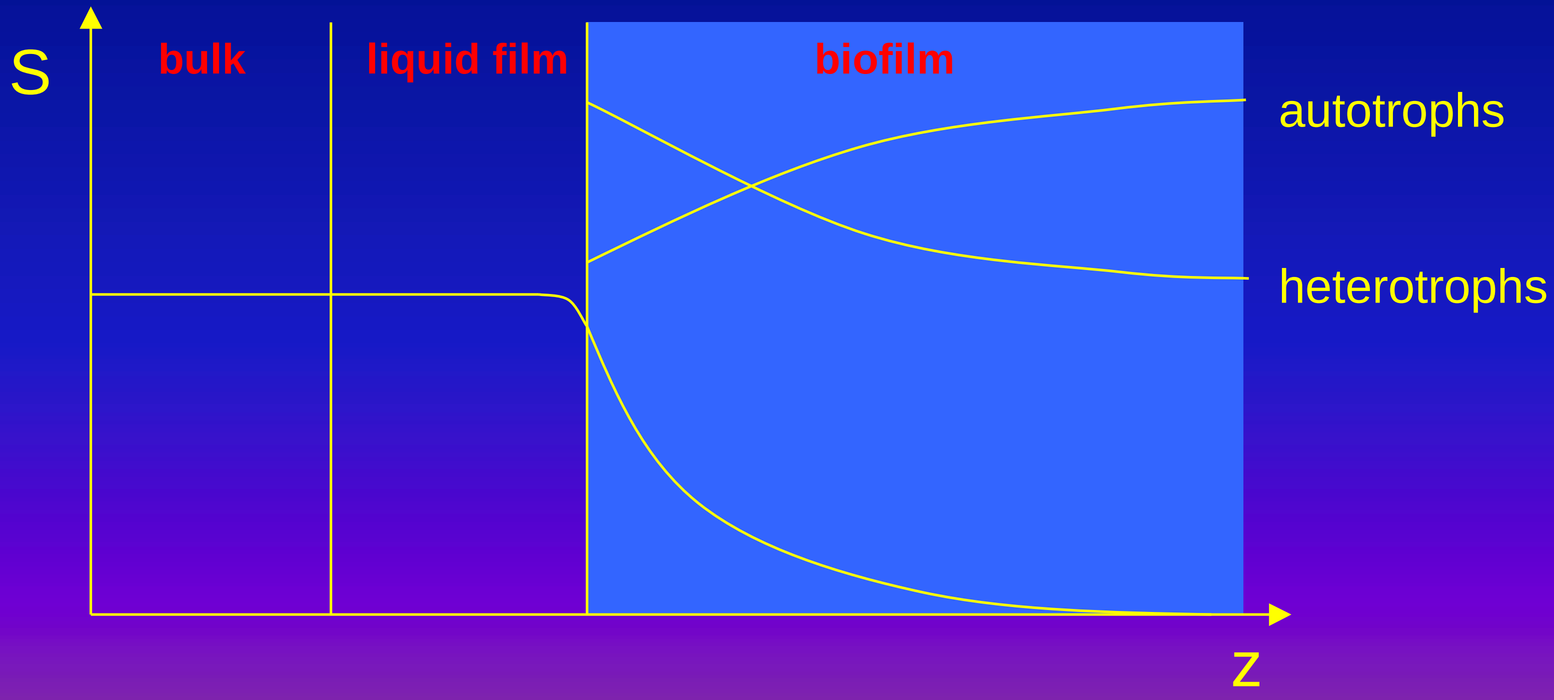
Biofilm Models Available (2)

- 1D models focussing on biomass distribution
  - Describe competition of different species
  - PDE-models



Biofilm Models Available (3)

- Multi-dimensional models
  - Heterogeneous biomass and substrate distribution in 2 or 3 dimensions
  - High performance computing necessary

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Practical Modelling Needs

- Describe plant dynamics
  - Response to influent variations
  - Off-line optimisation via scenario-analysis
  - On-line control and optimisation (real-time simulation)
- Troubleshoot
  - Give answers to practical questions on how to operate the plant
- Reactor design
  - Evaluate data from pilot plant
  - Predict full-scale operation

Difficulties of Practical Application (1)

High model complexity

- Considerable detail at the micro-scale
  - Influence of micro-scale on macro-scale reactor performance?
  - Too detailed for practical (on-line) applications
- Still, quite some important processes are poorly described:
  - Attachment and detachment, clogging and backwashing, influence of higher organisms, flow distribution, …
- A lot of parameters need to be calibrated. Most of them can not be measured directly

Difficulties of Practical Application (2)

Low model complexity

- Not able to describe all the dynamics of the system because of simplifications
- Lower amount of parameters: calibration easier

Adequate complexity: good balance between pro’s and con’s of different models

Case Study: The Aim

is to use
BIOFILM MODELS

to

improve the UNDERSTANDING of the
COMPLETE BIOFILM BASED PROCESS UNIT

and

to OPTIMISE the process where possible

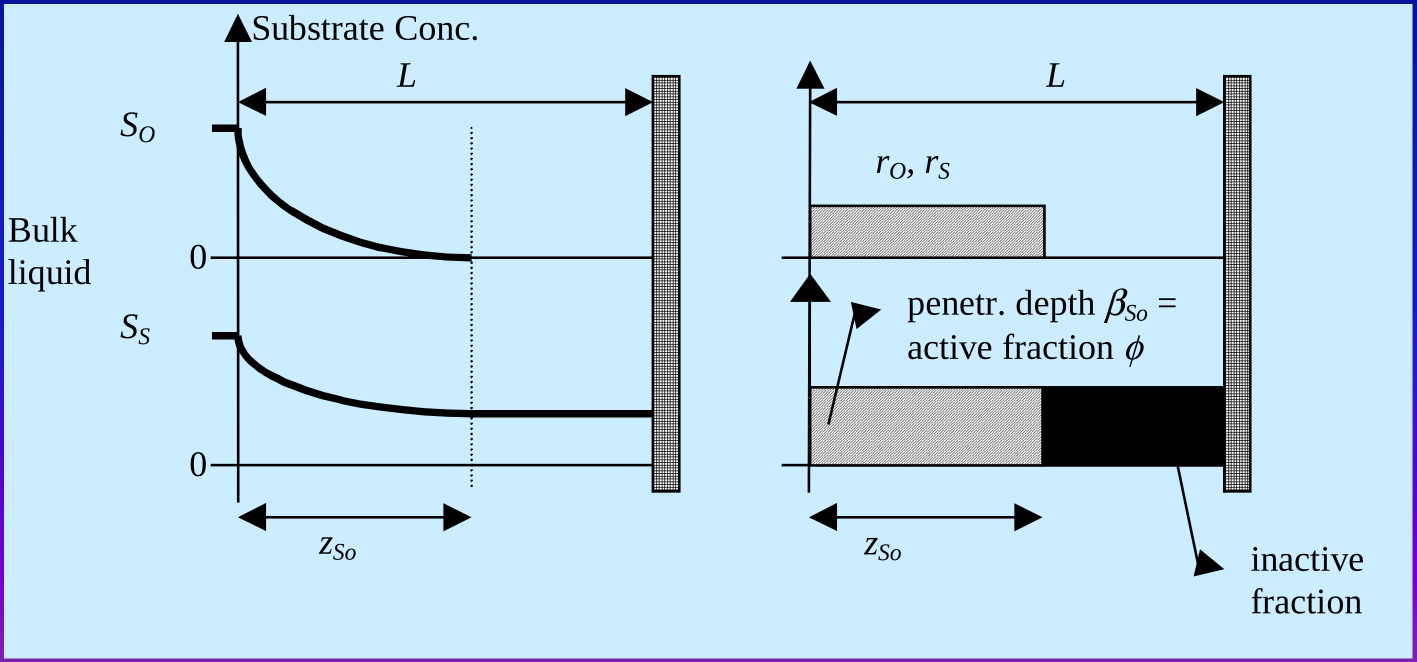
Model Building: a complexity compromise

MODEL : Rauch, Vanhooren & Vanrolleghem (1999)

Model solved by a two step procedure

(1) the active fraction of the biomass within the biofilm is computed

(2) all conversions within the biofilm are calculated using only the active fraction of the biomass in the biofilm



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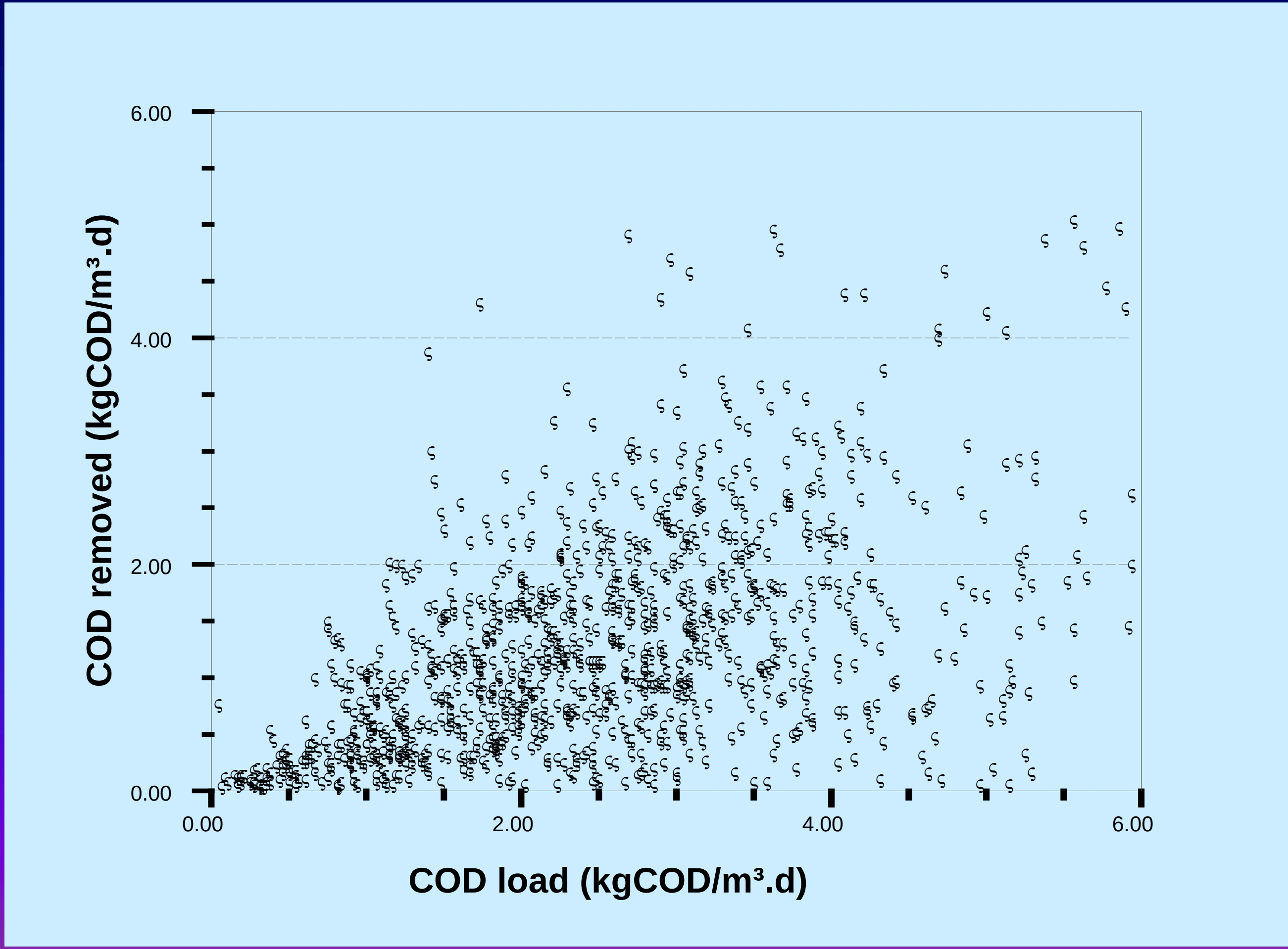
Case Study 1 (1)

- Trickling filter treating mainly domestic sewage wastewater
- COD load vs. COD removal:



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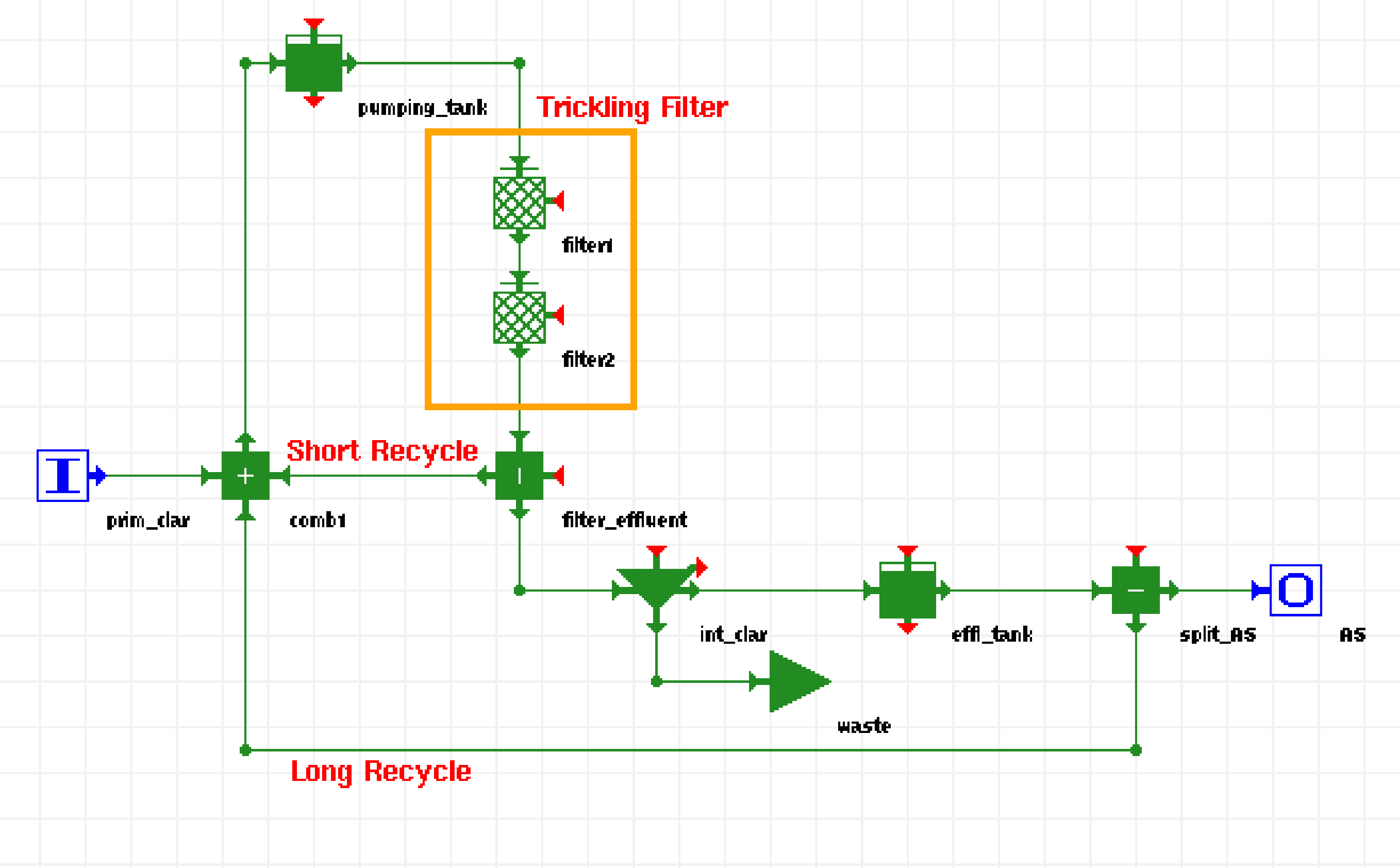
Case Study 1 (2)
Model Implementation (WEST®)



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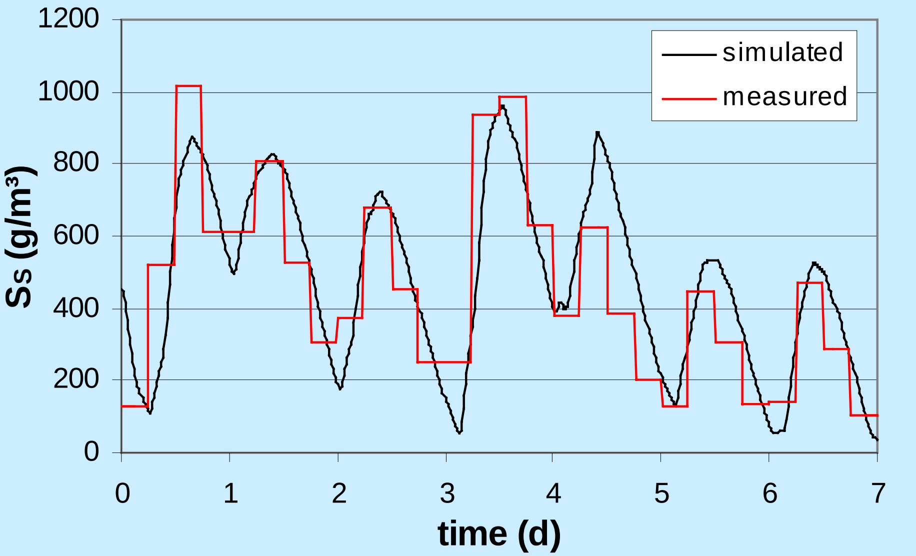
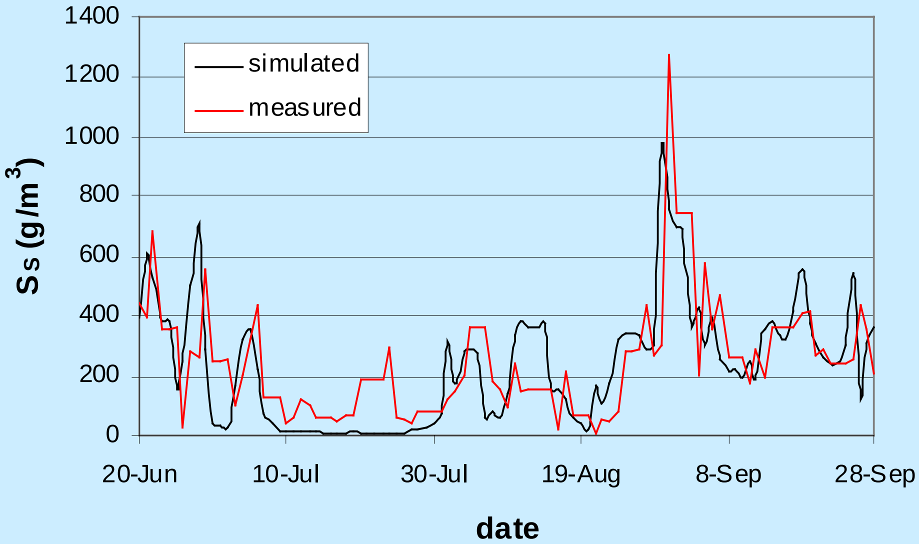
Case Study 1 (3)

- Calibration and validation, only off-line measurements
- Further model simplification: only carbon removal





- Maximum COD removal modelled : 2 kg COD / m^3.d

  <-> measured COD removal ??

- Be careful using point measurements.

Case Study 2 (1)

- Filter treating highly loaded industrial wastewater
- Load : 15000 kg COD/d
- Reactor Volume : 3160 m^3
- Average Flow Rate : 110 m^3/h
- Air Flow Rate
  - high flow : 17300 m^3/h
  - low flow : 10900 m^3/h

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Case Study 2 (2)
ON-LINE Measurement Techniques

respirometry

- RODTOX biosensor (Kelma bvba, Niel, Belgium)
- Load and toxicity monitoring
- Estimation of readily biodegradable COD

off-gas analysis: O_2 and CO_2

- Measurement is indication for complete reactor performance
- Clean and robust : no fouling, no chemicals, …
- Can be used to study
  – Oxygen and carbon mass balances.
  – Changes in load and process behaviour.

Case Study 2 (3)
Model Extension

extension for *IC* production and transport

$$
\begin{array}{llll}
CTR^{measured} & & CPR^{reality} & \\
\uparrow & & \downarrow & \\
CO_2^{(gas)} & \Leftrightarrow & CO_2^{(aq)} & \Leftrightarrow H_2CO_3 \Leftrightarrow HCO_3^- + H^+ \Leftrightarrow CO_3^{2-} + 2H^+
\end{array}
$$

kinetic modelling of CO_2 / HCO_3^- equilibrium
necessary : hydration of $CO_{2(aq)}$ is slow !!

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Case Study 2 (4)
Model Calibration

1. sludge balance : attachment / detachment

   SS and NH_4^+

2. effluent concentrations : growth / decay / yield

   basic question : oxygen of substrate limited system ??

   model predicts substrate limitation in ± 50% of time

3. off-gas concentration : K_La for O_2 and CO_2

   $(K_La)^{CO2} \approx 0.9 * (K_La)^{O2}$

1, 2 and 3 => iterative process !

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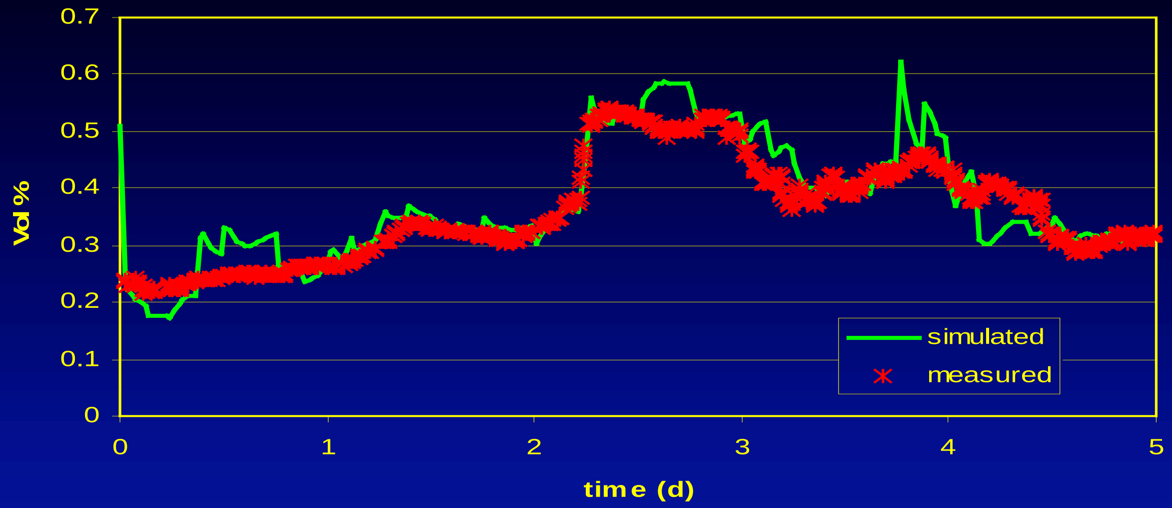
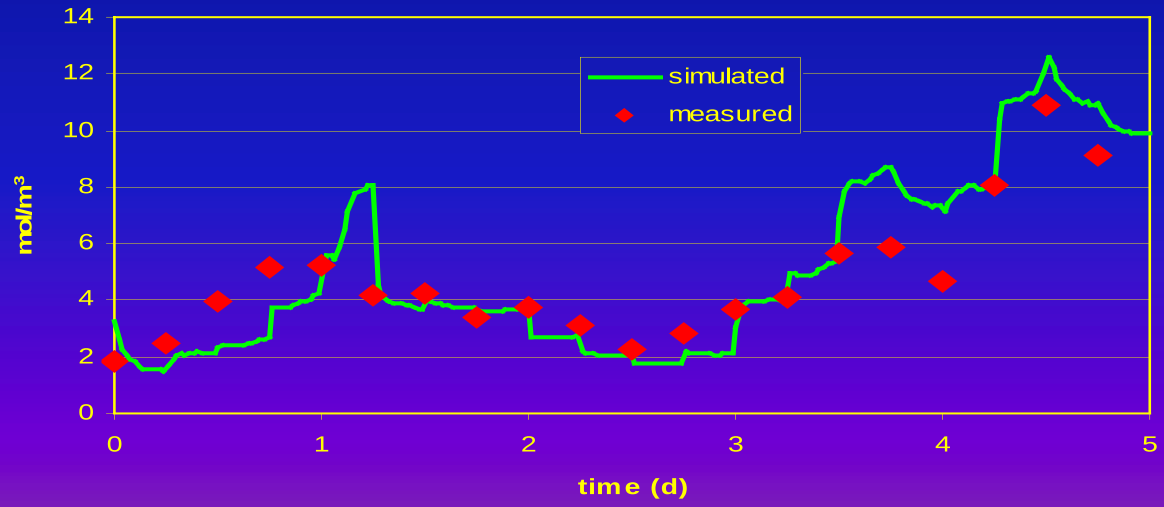
off-gas CO_2



effluent HCO_3^-



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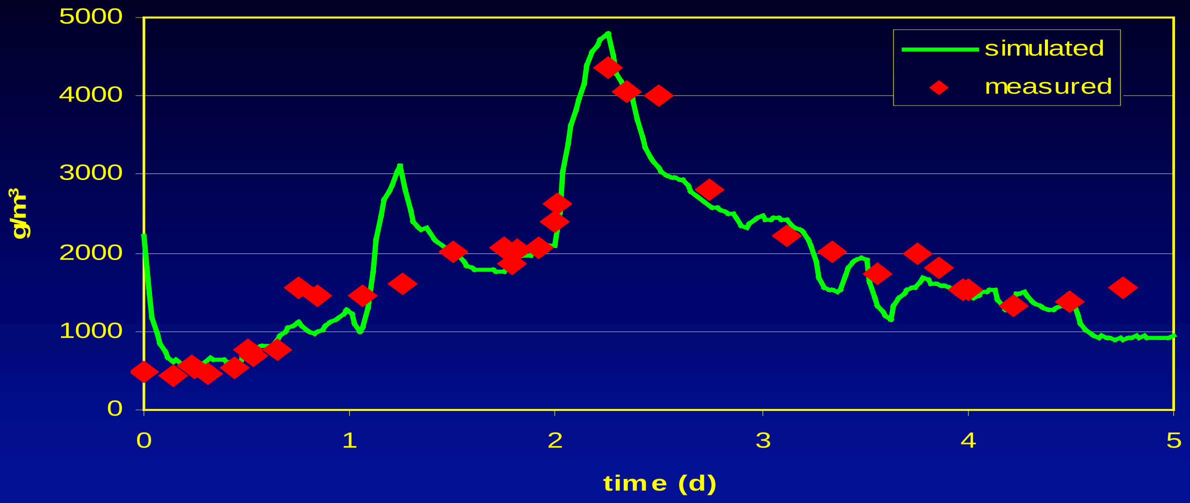
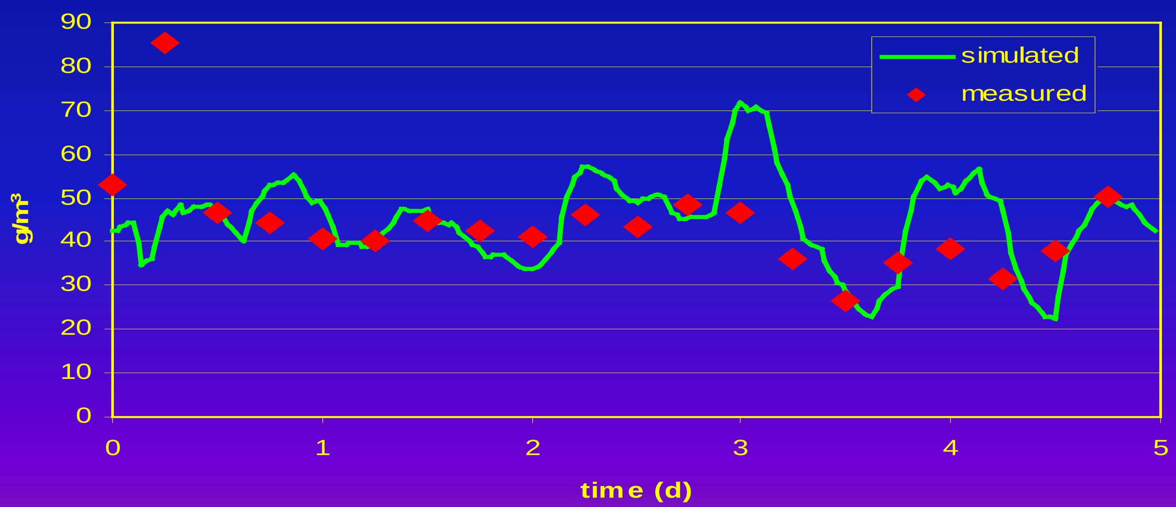
effluent readily biodegradable substrate



effluent ammonia



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Conclusions

- Biofilm model building
  - A lot of models are available
  - Compromise between complexity and calibration effort is to be found
  - Model used should be dependent on the goal of the modelling study

- Model calibration
  - Iterative process, highly dependent on the available data
  - Off-line measurements sufficient for relatively simple systems
  - On-line measurements can make calibration easier
    - Respirometry: estimate biodegradable COD
    - Off-gas analysis
      - Extra information for model calibration
      - *IC* - equilibrium modelling necessary